1. Header

Project Title: “A Subseasonal Excessive Heat Outlook System for CPCs Global Tropics Hazards and Benefits Outlook (GTH)”
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Program Officer: Daniel Barrie
Project Progress Report
Reporting Period: 05/01/2018 - 04/30/2019
Award Number: NA16OAR4310147

2.1 Final report

The first science problem that the project tackled was the quantification of the linkage between atmospheric fields (observed and forecast) and impacts on human health from heat stress. After a number of tests the project converged on the use of the Excess Heat Factor (EHF). Some modifications were applied in order to account for the impact of humidity on thermal discomfort. The 2-meter temperature was replaced by the apparent temperature which in this project was chosen to be the Heat Index as defined by NOAA. Additional modification had to be introduced in order to account for monsoonal regimes during which the humidity and the temperature are elevated without resulting to thermal stress. The first version of the operational subseasonal (Week-2) Excess Heat System was based on NOAA’s GEFS and was provided to the Climate Prediction Center. The second system extended the excess heat forecasts to week-3 and is based on NOAA’s CFS. The later system is running quasi-operationally daily and the experimental results are provided on the free access site: excess-heat.org which was developed by the PI. At this time the very active summer seasons of 2018 and 2019 are investigated.

Boreal summer 2019

The CFS based system was used in real-time during the Boreal summer of 2019. This season was very active. It is difficult to provide forecast scores other than a crude approximation based on only two seasons (2018, 2019). A discussion of the approximated scores is presented in Figure 14. A visual comparison of observed events (calculated based on ERA-Interim), and forecasts at specific cities (Chicago and Phoenix) are presented in Figure.Final.

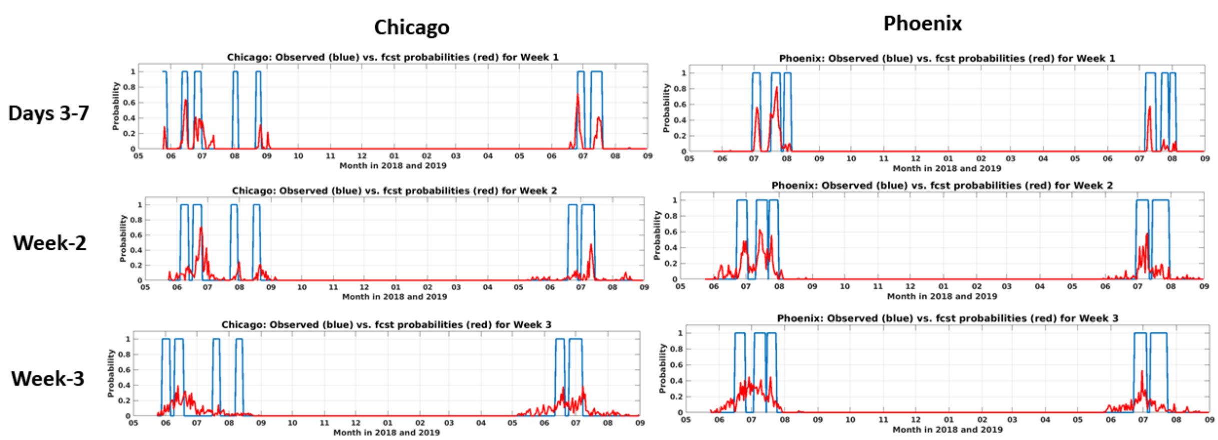

Figure.Final: Observed events (blue) during boreal summers 2018 and 2019 based on ERA-Interim data. An observed event occurs if the EHF exceeds the 50^{th} percentile. Red curves show the forecast probability of occurrence of the event.

Inspection of the above Figure shows that, as expected, it is more difficult to forecast events at week-3 than at days 3-7. Nevertheless, even for Days 3-7 there are cases where observed events were not forecasted. This findings motivate investigation of the critical physical processes that are relevant to the observed events and of which of these physical processes are parameterized based on wrong assumptions.

2.2 Main goals of the project, as outlined in the funded proposal

The scope of this project is to expand the Subseasonal Excessive Heat Outlook System (SEHOS-US) to the global tropics and subtropics (SEHOS-STROP) and extend the forecast horizon up to week-4 using prediction of temperature and humidity from multiple models. Our objectives are:

(1) Expand and refine the GEFS based excessive heat monitoring system to cover the tropics and subtropics and compile a list of heat events during the reforecast period.

(2) Expand and refine the GEFS based Week-2 forecasting system to cover the tropics and subtropics and estimate forecast skill for the events detected on (1).

(3) Use results from currently ongoing research to provide multi-'operational'-model input to the SEHOS-STROP for forecasts of heat events at Week-2 and extend these forecasts to Week-4.

3. Results and Accomplishments

Motivation

The development of the Global-SEHOS, which encompasses the Tropical-SEHOS, is justified by the expectation that early warning operational systems will facilitate relief agencies and the health sector to cope with rising morbidity/mortality due to more intense and frequent excessive heat events and a population that is growing older.

Past work

The first phase of this project developed and transitioned the legacy-GEFS based Global-SEHOS to TRL7 computing in real time Week-2 forecasts of excessive heat events worldwide. These forecasts were communicated daily to NOAA's Climate Prediction Center during the boreal summer of 2017 and then the entire system was provided to CPC forecasters. These excessive heat event (EHE) forecasts with the GEFS used a simple baseline definition of heat waves that was introduced to test the feasibility of health impact oriented subseasonal forecasts of excessive heat. It was shown that health oriented metrics are predictable depending on the geographical location up to Week-3 (Figure 1).

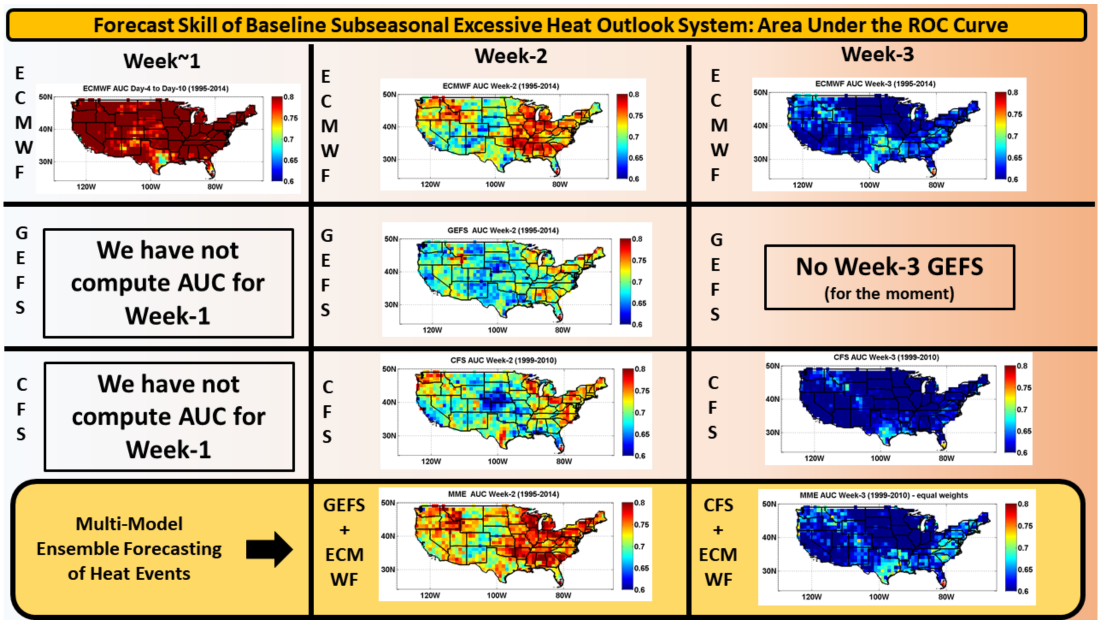

Figure 1: Forecast scores for the baseline GEFS based system. The forecast metric used here is the area under the ROC curve (AUC). The first row shows the decrease of forecast skill from Week-1 to Week-3 with the ECMWF model. Row 2 shows results from the GEFS and row three shows results from the CFS. It is interesting to note that the fastest rates of skill drop are located in the central United States. The last row indicates that multi-model approaches are increasing forecast skill.

The next step was the adoption of a more sophisticated metric of impacts of excessive heat on human health: the Excess Heat Factor (Nairn and Fawcet, 2016) that models the acclimatization of the human body to heat. It was then shown that in order to differentiate events that resulted in significant mortality an extended ('wet') version of the EHF had to be introduced (Figure 2).

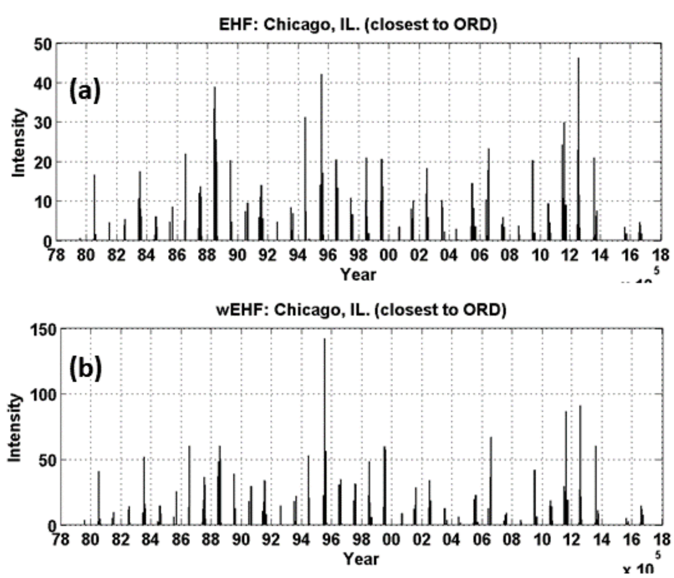

Figure 2: (a) Amplitude of the standard EHF for Chicago, IL based on ERA-Interim data. The 1995 event is clearly captured but it is only ranked second - not much stronger than the third event in rank (1988). The contrast between impacts from the 1995 and 1999 events due to acclimatization and the harvesting effect is clearly

captured. (b) The modified EHF index that includes humidity information through the use of NOAA's heat index shows that the 1995 event was much worse than any other event within the 1979-2016 period.

The 'core' model of the system was transitioned from the legacy-GEFS to the coupled ocean – atmosphere - land CFSv2. Sophisticated bias correction techniques based on quantile mapping were developed to address bias correction at the tails of the distribution of the relevant environmental variables (Figure 3). Finally, the first version of powerpoint presentation for communicating real time monitoring and forecasts was created.

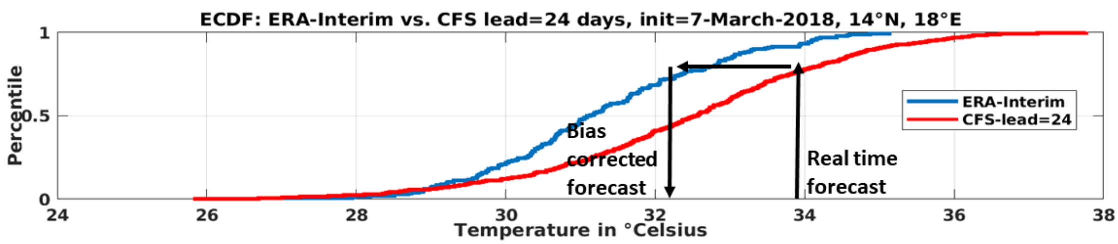

Figure 3: The bias correction methodology is based on quantile mappings. The empirical cumulative distribution function is computed for each grid point within a time window of 7 days and for each forecast lead day for the observations (ERA-Interim) and the model. Real time forecasts are then projected using these CDF. It should be noted that the process is non-linear as the mapping depends on the forecast temperature.

Current work

Further refinement of the metric of the health impacts of excessive heat had to be introduced in order to address issues revealed during real time forecasting. Special attention had to be given when calculating the wet EHF during monsoons. In fact, during active monsoon phases the heat index is high as a result of warm temperatures and elevated humidity. However, heat is not a health hazard during the rainy season. Therefore methodology to switch the apparent temperature to air temperature during active monsoon phases but not during monsoon breaks had to be developed. Figure 4 uses METAR observations to show an example of the developed methodology in New Delhi during 2015. The red curve shows the annual evolution of the air temperature, the blue line shows the heat index and the black line shows the operative temperature provided by the methodology developed by the PI. It is seen that during the pre-monsoonal season the effective temperature follows the heat index. After the monsoon onset the effective temperature is the air temperature with the exception of the first half of September. Inspection of Figure 5 which shows observed outgoing longwave radiation (OLR) anomalies shows that the first half of September was characterized by a monsoon break.

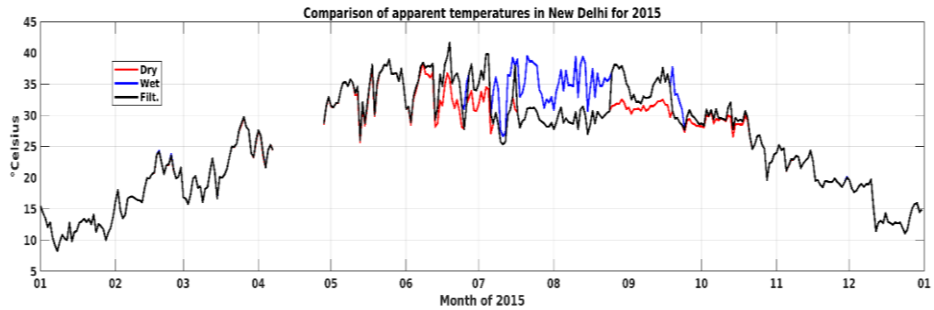

Figure 4: Air (dry) temperature (red) versus heat index (blue) versus effective temperature (black) during 2015 in New Delhi. Data are METAR observations.

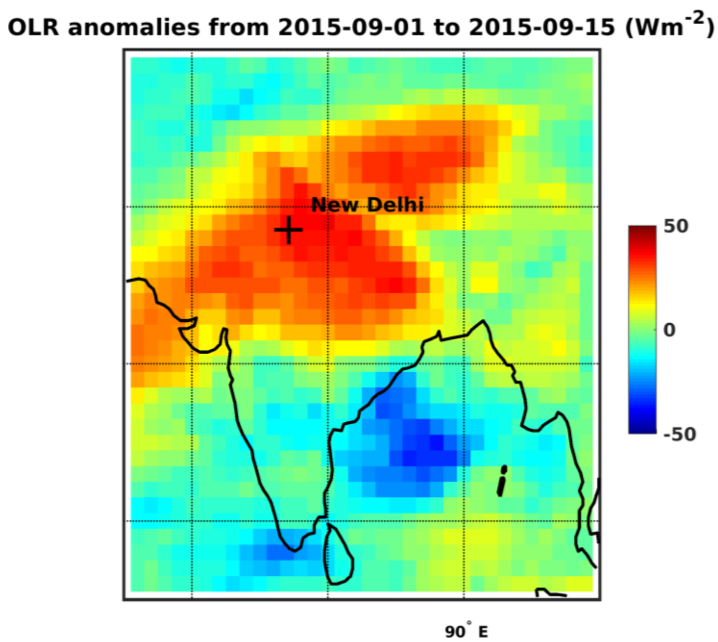

Figure 5: Observed outgoing longwave radiation (OLR) anomalies. Positive anomalies is an indication of suppressed convective activity.

An additional variant of the EHF metric had also to be introduced to address cumulative effects of long lasting excessive heat events of relatively low intensity. This effect is demonstrated in Figure 6 where I am using METAR observations to calculate the EHF in Moscow. It is well documented that 2010 was the deadliest year related to heat with at least 15,000 casualties in Moscow. Figure 6a depicts the instantaneous (daily) EHF. It is clear that 2010 is not among the hottest years. However, when the EHF is integrated for the duration of each event (Figure 6b) year 2010 becomes exceptional. It follows that a metric integrating the EHF during the duration of individual events in addition to the maximum value of EHF during an event needs to be introduced.

Finally, the geographical locations where the extended EHF represents better health hazards due to excessive heat are shown in Figure 7; these areas are located over major population centers.

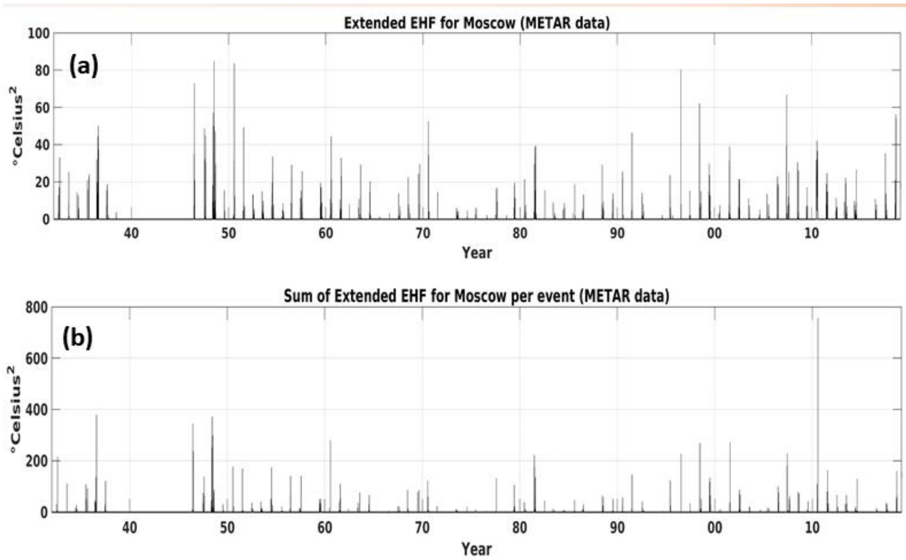

Figure 6: EHF values computed using METAR observations in Moscow: (a) instantaneous (daily values, and (b) integrated EHF for the duration of each excessive heat event.

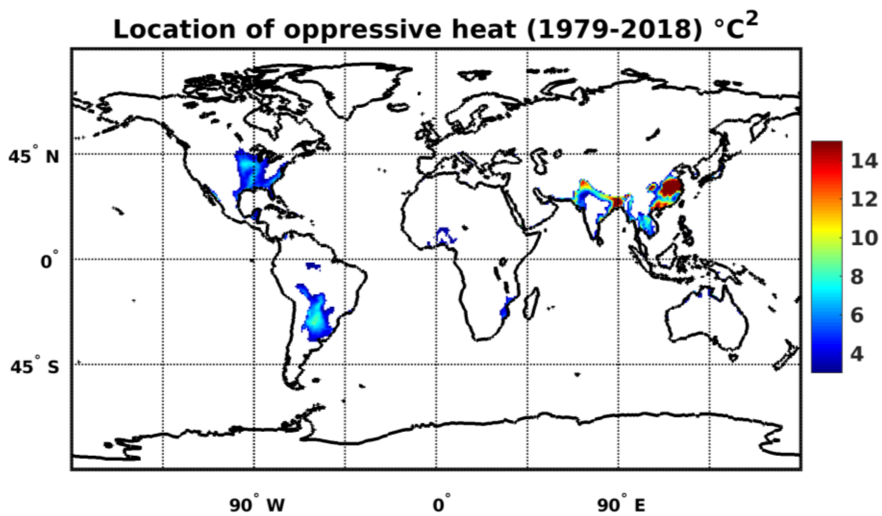

Figure 7: Mean difference of wet and dry EHF for the period 1979-2018. Geographical locations where the extended (wet) EHF represents the effects of heat on health better than the standard EHF are located over major population centers.

The decision to transition the core forecast system from the GEFS to the CFSv2 was based on published hypotheses stating ocean – atmosphere coupling as a factor in the transition of atmospheric circulation to a quasi-stationary wavenumber 5-7 Rossby wave. In addition, the capacity of the CFSv2 to forecast the EHF was documented by Ford et al. (2018). The legacy GEFS was not a coupled model and extended to forecast day 15 only. The newer version of the GEFS which participates in the SubX experiment and extends to forecast lead day 35 is not fully coupled as it uses sea surface temperature from CFSv2 forecasts. Lastly, despite the higher horizontal resolution of the GEFS it is not known whether the additional grid points are sufficient for a better representation / forecast of the transition to high wavenumber quasi-stationary Rossby waves.

A number of initial diagnostics was conducted in order to quantify how well processes relevant to excessive heat are represented by the CFSv2. I used three forecast score metrics to investigate how well the CFSv2 is reforecasting weekly mean 2-meter temperature and relative humidity. These diagnostics are global but for lack of space in this report I only present results over the Contiguous United States. Similarly to results shown in Figure 1 the forecast score of 2-meter temperature is minimum in the middle part of the CONUS. For 2-meter relative humidity the middle of the CONUS is also characterized by low scores but the lowest scores are seen in the Midwest.

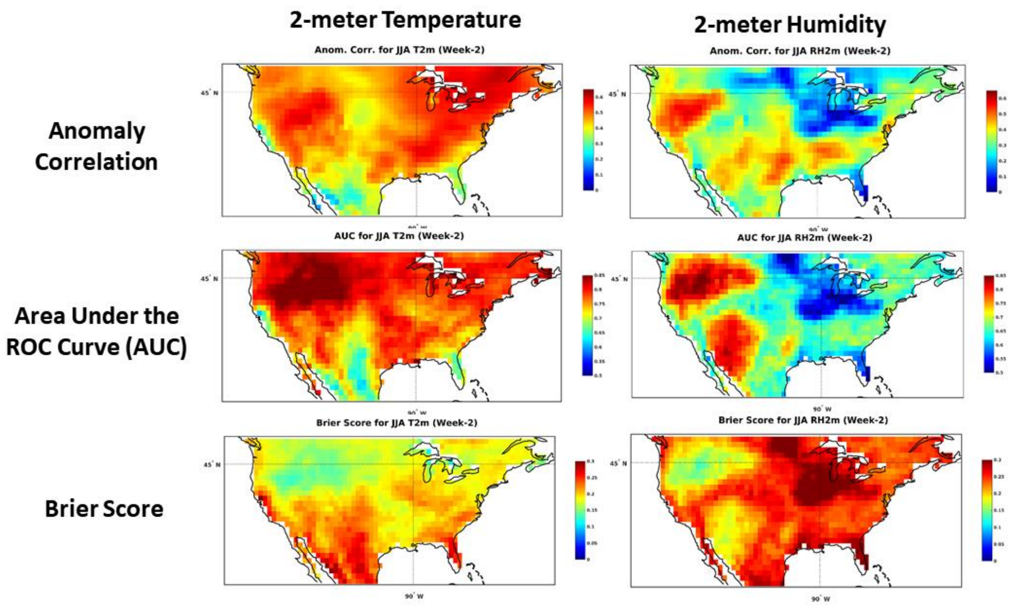

Figure 8: Reforecast scores for 2-meter temperature (left column) and relative humidity (right column) at Week-2. The first row shows anomaly correlation of the forecast ensemble mean and ERA-Interim, the second row shows the area under the ROC curve (AUC) for the forecast event being exceedance of the 66th percentile, and the third row depicts the Brier score for the same forecast event.

Figure 9 provides evidence for the reasons of these forecast score minima. The minimum of 2-meter temperature forecast scores (that are also seen in Figure 1) correspond to a ‘hot spot’ for land-surface / atmosphere (boundary layer) coupling (Koster et al., 2014). This is a strong evidence that models (even the ECMWF – Figure 1) are not representing adequately coupled land-surface / atmospheric boundary layer processes. The ‘corn-belt’ shown in Figure 9b is collocated with the minimum of 2-meter humidity forecast score. This is an indication of the misrepresentation of vegetation in this area by the NCEP suite of models (ECMWF has a better score in this area than both GEFS and CFS; see Figure 1). This diagnostic analysis suggests that better understanding and modelling of coupled land-surface / atmospheric boundary processes must be prioritized.

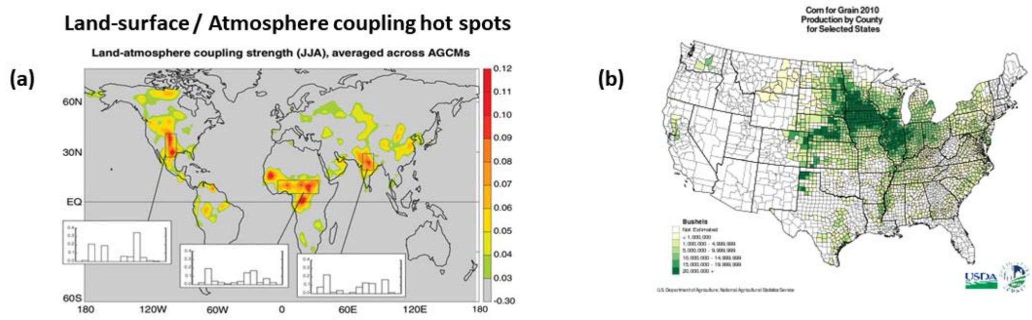

Figure 9: (a) Land surface / atmosphere coupling hot spots detected by Koster et al. (2014), and (b) corn production during summer 2010.

Experimental quasi-operational forecasts and monitoring with the CFSv2 based Global-SEHOS started in May 2018. These daily forecasts and monitoring were summarized and transmitted bi-weekly worldwide to an e-mail list of 90 members. After requests from the users I developed a website: excess-heat.org which is presenting real time monitoring and forecasts that are updated daily since January 2019. As of May 29th, 2019, EST-COB the website has been visited from the United States, Philippines, Canada, France, Italy, China, Russian Federation, Great Britain, Ireland, Germany, Netherlands, Israel, Brazil, Sweden, and Turkey. The number of unique visitors per month is shown on Table 1.

January	February	March	April	May
56	154	86	143	136

Table 1: Unique visitors of the website excess-heat.org per month during 2019

An issue that had to be addressed is the relevance of the chosen metric (EHF) to excessive heat events occurring around the world. This is particularly important for the monitoring system which also serves for the forecast verification. The problem is that there are no publicly available real time data of heat related injuries/deaths even in developed countries e.g., the United States. I bypassed this problem by verifying whether there were news reports from areas in which the EHF was indicating to be under excessive heat conditions. An example of this verification methodology is shown in Figure 10 which compares monitoring of an excessive heat event that occurred in Scandinavia during summer 2018 with a news report from Time magazine.

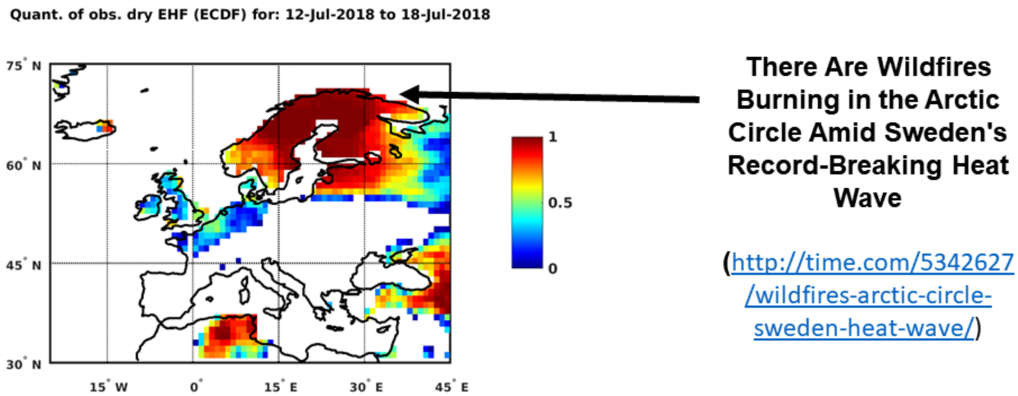

Figure 10: Validating the relevance of the EHF metric to excessive heat events through new reports

Many heat events occurred during the North Hemisphere warm season of 2018; the term global-heat-wave appeared on the global press. For example time series of the EHF from 1979-2018 in Chicago is shown in Figure 11. Summer 2018 was ranked 11th in the period 1979-2018. The strongest three events occurred in late June (3-day event), in mid-July (2-day event) and early July (3-day event).

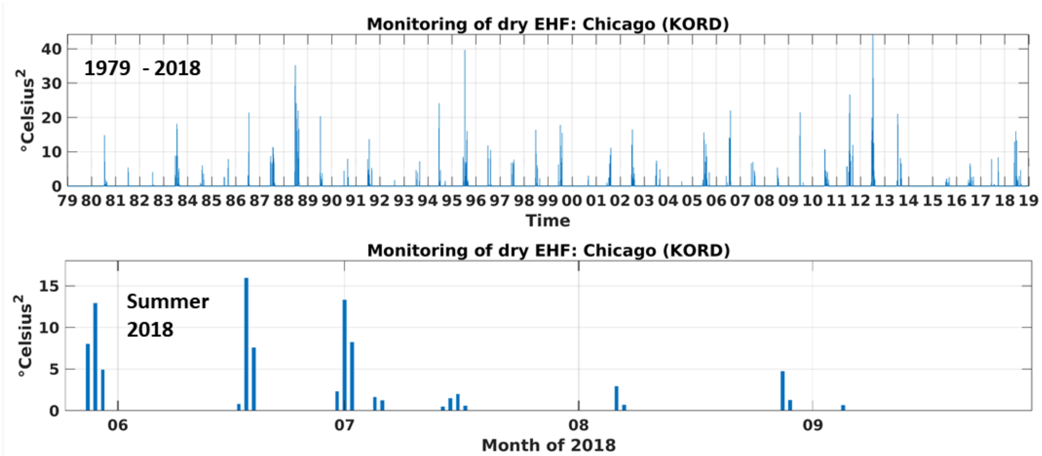

Figure 11: The dry EHF for Chicago (KORD) during 1979-2018 (upper panel), and during summer 2018 (lower panel).

Figure 12 shows ensemble forecasts of daily dry EHF for initializations of the CFS at different temporal distances from the third heat event that occurred in Chicago. Even when initialized three weeks prior to the event there is some indication of oncoming activity. As the CFSv2 is gradually initialized closer to the event more ensemble members indicate an oncoming heat event. It is interesting to note that forecasts show an oncoming heat event that precedes the observed event by 1-2 days and that once the model heat event occurs many ensemble members persist it even after the termination of the observed heat event. This suggest misrepresentation of land surface / atmospheric boundary layer coupling and/or a land surface that is drier than observation during initialization.

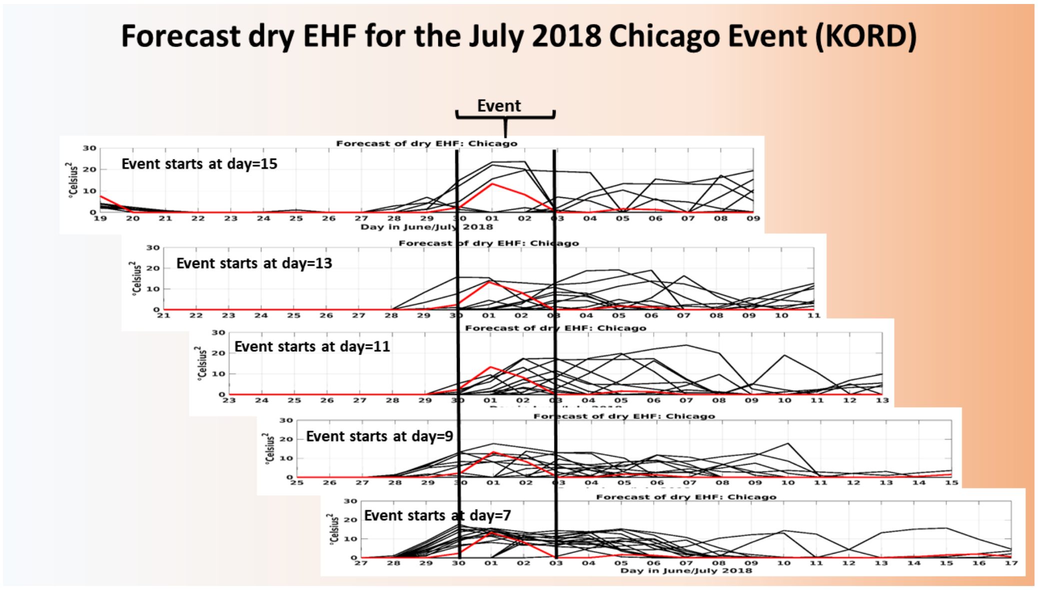

Figure 12: Ensemble daily dry EHF forecast for successive initializations of the CFS from 15 days prior to the event to 7 days prior to the event. The red line is verification computed using ERA-Interim.

Figure 13 depicts the number of days with dry EHF that exceed the 50th percentile in the period 2018-05-25 to 2018-09-15 for the CONUS and Europe. In the CONUS maxima of number of hot days are seen in the southwest (with the exception of Arizona and Utah), the northwest, the eastern Midwest and the north east. The western Midwest and the Southeast experienced a lower number of hot days. North and Western Europe was anomalously warm during summer 2018 with the highest number of hot days in Sweden (over 30) while there were no hot days in the Balkan Peninsula.

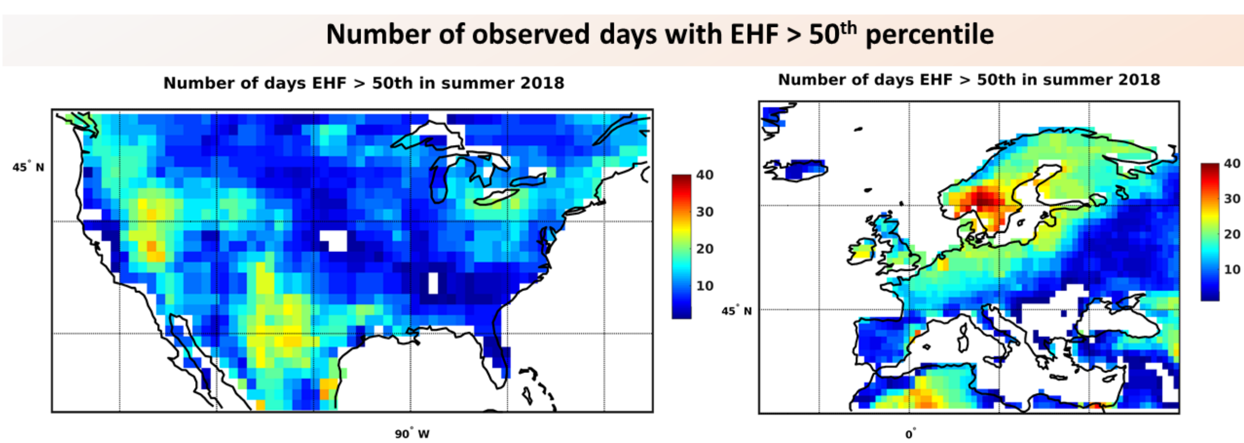

Figure 13: Number of days with dry EHF exceeding the 50th percentile. The observed EHF is calculated using ERA-Interim data.

The Brier skill score for the CONUS and Europe are shown in Figure 14. The event to be forecast is: at least one day with EHF exceeding the 50th percentile during a given period (Days 3-7, Week-2, and Week-3). The baseline forecast methodology for computing the skill score is climatology i.e., no-event. Columns represent forecasts for Days 3-7, Week-2, and Week-3 respectively. There is a number of caveats to be considered before interpreting these results. Most of these days are clustered in a small number of heat events. In addition, the same heat event is 'seen' by successive initializations of the CFS thus there is serial correlation among the forecast samples which is not accounted for. As expected forecast skill decreases gradually with increasing lead time but the rate of decrease depends on the geographical location. Over the CONUS the smallest rate of decrease can be seen in the northwest. In Europe the forecast skill remains high even for Week-3 in France, Germany, Poland, and Scandinavia. One of the reasons for the location dependence of the rate of drop of forecast skill is the varying number of hot days (Figure 13). However, deficits of soil moisture has been associated with higher probability for heat waves. Therefore a hypothesis to be tested is that persisting substantial negative soil moisture anomalies occurred in the areas were the skill extends to Week-3 and that the model captures the increased probability of heat wave occurrence when initialized with such conditions.

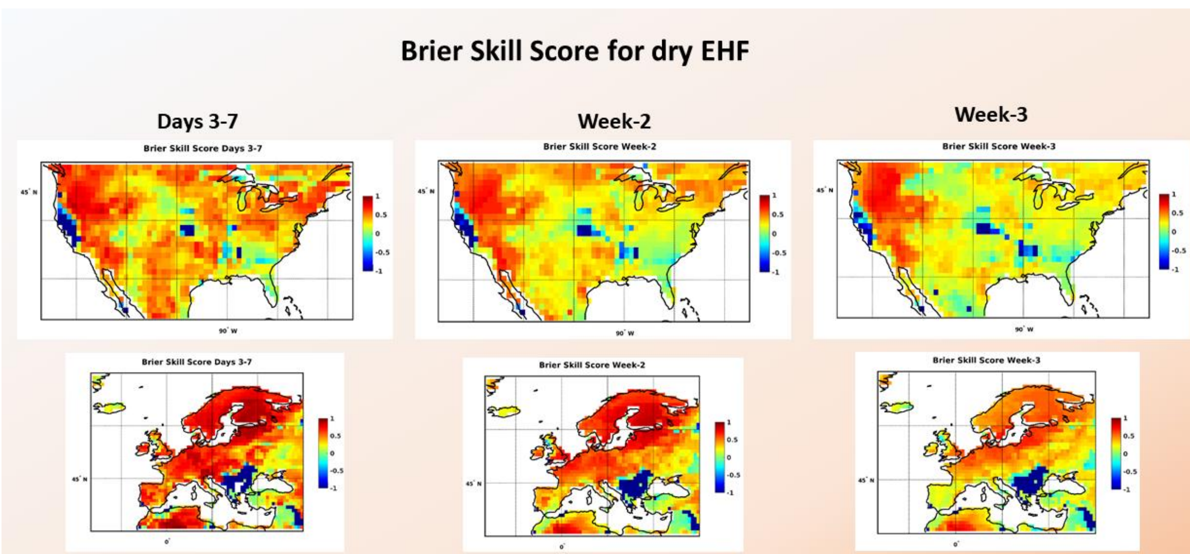

Figure 14: Briar skill score for dry EHF calculated for initializations between 2018-5-25 and 2018-9-15. The baseline forecast is climatology i.e., no-event forecast

4. Highlights of Accomplishments

- Further refinement of the excessive heat metric (EHF) that now takes into account active monsoon phases and monsoon breaks, and adds the integrated EHF during heat events.
- Distribution of real time global forecasts and monitoring using a digital (powerpoint) presentation which was sent twice weekly to an e-mail list of 90 members across the world.
- Introduced the Days 3-7 forecasts.

- Developed a website (excess-heat.org) that distributes forecasts of excessive heat events for Days 3-7, Week-2, and Week-3 that is updated daily.
- Evaluated forecast skill scores during the Northern Hemisphere summer of 2018 and the Southern Hemisphere warm season of 2018/2019 using the ERA-Interim reanalysis.
- Initiated process oriented diagnostic studies to understand reasons for forecast errors in specific geographical locations prioritizing the United States.

5. Transitions to Operations (applied use)

The CFS based Global-SEHOS is executed daily. Experimental forecasts are disseminated through a website and are freely available. The software is open-source and will be freely available when optimized and fully documented.

6. Estimate of current technical readiness level of work

TRL7: The CFS based prototype system is used daily and provides forecasts of excessive heat outlooks for Days 3-7, Week-2 and Week-3.

7. Publications and Presentations from the Project

Publications in preparation:

(1) A Metric for Quantifying the Intensity of Excessive Heat Events at Global Scale

(2) Evaluation of Quantile Mappings for Bias Correcting Forecasts of Excessive Heat Events

(3) Global predictability of Oppressive Excessive Heat Events at Subseasonal Timescales

Presentations:

Vintzileos, A., 2019: A Real-time Subseasonal Forecast and Research System for Excessive Heat and Health. AMS Annual Meeting, Phoenix D.C.

Vintzileos, A., 2018: A Real-time Subseasonal Forecast and Research System for Excessive Heat and Health. AGU Fall Meeting, Washington D.C.

Vintzileos, A., 2018: Excessive Heat Events and Health: Health-Impact Oriented Subseasonal Excessive Heat Outlook System. WMO - Second International Conference on Subseasonal to Seasonal Prediction (S2S). Boulder, CO.

Vintzileos, A., 2018: Climate Variations/Change & Health. (INVITED) US-CLIVAR PPAI Panel, Boulder CO.

Vintzileos, A., 2018: Building Subseasonal Outlook Systems: The Case of Excessive Heat Events and Health (SEHOS) Application to assist in subseasonal outlooks of ocean conditions. (Invited) USAID/INSTM, May 2018, Tunisia.

Vintzileos, A., 2018: Excessive Heat Events and Health: Building Resilience based on Subseasonal-to-Seasonal Excessive Heat Outlook Systems. 98th Annual Meeting of the

American Meteorological Society, Ninth Conference on Environment and Health. Austin, Texas.
Vintzileos, A. 2017: Elements of a subseasonal-to-seasonal excessive heat outlook system (SEHOS). CICS annual meeting, 6-8 November, College Park, MD.
Vintzileos, A. 2017: Enhancing Resilience to Heat Extremes: Multi-model Forecasting of Excessive Heat Events at Subseasonal Lead Times, 21st International Congress of Biometeorology, 3-7 September, Durham, UK.
Vintzileos et al., 2017: Towards Improved Worldwide Forecasts of Excessive Heat Events at Subseasonal Lead Times, MAPP-PI meeting, 2-3 August, College Park, MD.
Vintzileos et al., 2017: Enhancing Resilience to Heat Extremes: Multi-model Forecasting of Excessive Heat Events at Subseasonal Lead Times. American Meteorological Society Annual Meeting, 22-26 January, Seattle, WA.
Vintzileos et al., 2016: Enhancing Resilience to Heat Extremes: Multi-model Forecasting of Excessive Heat Events at Subseasonal Lead Times. S2S Extremes Workshop at International Research Institute for Climate and Society. 6-7 December, Palisades, NY.
Vintzileos et al., 2016: Enhancing Resilience to Heat Extremes: Multi-model Forecasting of Excessive Heat Events at Subseasonal Lead Times. 12-16 September, American Geophysical Union, Fall Meeting, San Francisco, CA.
Vintzileos et al., 2016: Enhancing Resilience to Heat Extremes: Multi-model Forecasting of Excessive Heat Events at Subseasonal Lead Times. 3-6 October. NOAA's 41st Climate Diagnostic and Prediction Workshop. Orono, Maine.
Vintzileos, A. 2016: Extreme Heat and Health: Towards Multi-Model Ensemble Forecasting of Excessive Heat Events at Subseasonal Lead Times (Week-2 to Week-4). George Mason University-COLA (INVITED), 28 June, Fairfax, VA.
Vintzileos, A. et al., 2016: Extreme Heat and Health: Towards Multi-Model Ensemble Forecasting of Excessive Heat Events at Subseasonal Lead Times (Week-2 to Week-4). CICS Executive Board Meeting (INVITED), 16 May, College Park, MD.

8. PI Contact Information

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